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Biostratigraphy and Palaeoenvironment of the Upper Jurassic-Lower Cretaceous of Antsalova-Morondava basin-Madagascar

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ABSTRACT

Biostratigraphy and paleoenvironment of the Upper Jurassic - Lower Cretaceous in Antsalova site are determined by micropaleontological study. The sediments collected in the field will pass physico-chemical treatments and geochemical analyzes in the laboratory. The sedimentary deposits of the Antsalova site have delivered a microfaunistic association constituted by Foraminifera: 18 species of benthic Foraminifera, grouped into 6 Families and 2 species of Ostracoda belonging to a single Family. Planktonic Foraminifera are absent in all the formation. This formation is subdivided into three levels by these microfaunal associations encountered and corresponds to stratigraphic stages ranging from the Callovian to the Hauterivian. The major elements (SiO2, CaO, MgO) of the sediments, as well as the microfauna encountered, indicate a shallow marine environment (0 to 200 meters), with normal salinity and a hot climate. Microfossils geographical distribution and resemblance observed in this site, in many deposits of Madagascar,and the different world countries are related to the Ocean opening and the Tethys subduction.

Keywords: Foraminifera-Ostracods-stratigraphy-geochemistry-paleogeography.

1. Introduction

The Jurassic - Cretaceous interval is an important period in biological diversification at which many geological phenomena have occurred. The sedimentary series relating to this period is widely represented in the northern part of the Morondava basin, particularly the Antsalova site. Research work on sedimentary geology and/or paleontology has been carried out in this basin, namely the geological synthesis and paleontological studies of sedimentary lands in Madagascar (Besairie and Collignon, 1966 - 1971), the biostratigraphy and sedimentology of the Callovian -Cenomanian in Antsalova region (Ranarison, 1988), the identification of Jurassic microfossils from the Morondava Basin (Andriamalala, 1995),… And in this area, microfossils remain important temporal and biostratigraphic markers in sedimentary soils. The objective of this work is to determine the stratigraphic limits for the Upper Jurassic-Lower Cretaceous sedimentary formation in the Antsalova site through the study of the faunal associations encountered. The principle consists an inventory of the microfossils (Foraminifera, Ostracods, etc.), studying faunal associations and carrying out a geochemical analysis of the sediments in order to provide details for the paleoenvironment reconstitution, as well as the paleobiogeography in the site.

2. Geological context

The sedimentary series in the northern part of the Morondava basin, parallel extend the base following the NNW-SSE direction. The division of the basin into two North and South sub-basins is evidenced by the bundles of the Ilovo and Mandabe faults for the southern part and the Bekopaka Bemaraha fault in the North zone in the southern part of the basin, the contact of the series sedimentary with the basement is faulted, in a major direction NNE-SSW. Overall, this part has a relatively flat geomorphology, marked by coasts corresponding to the erosion or tectonic cliff facing the east (Razafimbelo, 1987).

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The general morphology of this basin is related to its tectonic style. Antsalova forms a series of small hills in the Antsingy Depression and the Cretaceous Plateau. This formation is characterized by glauconious marls and Duvalia marls which are often very clayey.

3. Materials and methods

The study site is located 17 km south of Antsalova village, near Tsingy de Bemaraha National Parks, belonging to Antsalova District, Melaky region, Mahajanga Province. Samples were collected from the sediment in place, unaltered with geographic coordinates: 18 ° 41 '50.7' 'South latitude and 44 ° 37' 14.3 'East longitude.

Figure 1: Location of the study site (Data FTM, BD 500).

The sediments collected on the field will continue physicochemical treatments and geochemical analyzes in the laboratory. Sorting and counting of microfossils is necessary in order to establish the relative frequencies of the different taxa and also for statistical chi-square calculations (test of independence).

Independence test

The independence test makes it possible to verify the independence between the taxa (species) and the different levels (I, II and III) of the studied site. This test is intended to compare the value of X_c^2 calculated with X_t^2 threshold read in the chi-square table for a fixed risk of error and (r_1-1) (r_2-1) degrees of freedom.

Hypothesis

H_0: taxa distributions and levels are two independent variables in the Antsalova site.

H_1: Taxa distributions and levels are not independent in the Antsalova site.

Decision rule

The significance level is 0.01

If X_c^2 calculated is greater than X_t^2threshold read in the chi-square table for a fixed risk of error and (r1-1) (r_2 -1) degrees of freedom, the null hypothesis is rejected.

If X_c^2 calculated is less than X_t^2threshold read in the chi-square table for a fixed risk of error and (r_1-1) (r_2 -1) degrees of freedom, the null hypothesis is accepted.

With: r_1: site modality, r_2: taxa modality by level.

Hypothesis

H_0: taxa distributions and levels are two independent variables in the Antsalova site.

H_1: Taxa distributions and levels are not independent in the Antsalova site.

4. Results and interpretation

Lithostratigraphy

The lithological section of Antsalova generally consists of greenish yellow marls with Belemnites and Ammonites, with a thickness of about 15.5 meters. As part of this work, five samples were taken from this site: ATL 1, 2, 3, 4, 5. It is made up from bottom to top by:

ATL1: yellowish gray marl,

ATL2: yellow to green marl,

ATL3: greenish marl spotted with yellow,

ATL4: greenish friable marl with Belemnites and *Aptychus*,

ATL5: greenish Belemnite marl with grains of sand on the upper surface.

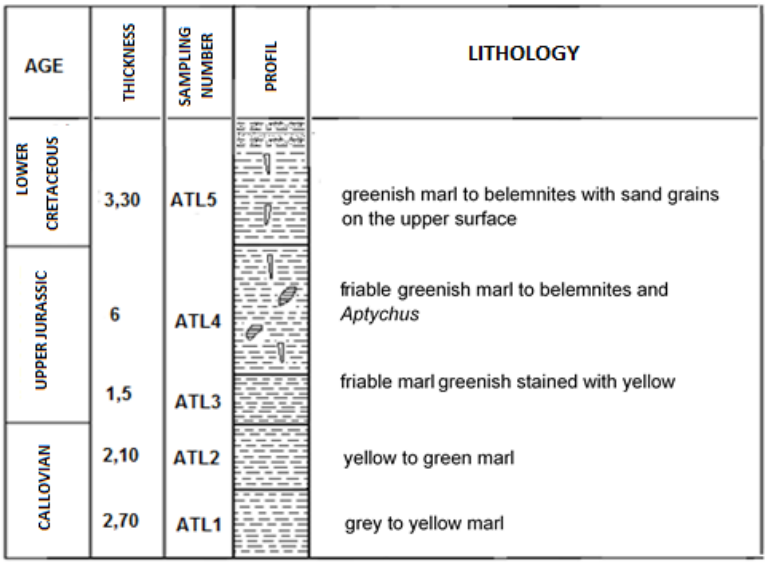


Figure 2: Lithological section of Antsalova (*scale: 1/100, ATL: Antsalova*)

Faunistic composition

The sedimentary deposits in the Antsalova site have yielded a microfaunal association consisting of Foraminifera: 18 species of benthic Foraminifera grouped together in 6 families and 2 species of Ostracods belonging to a single Family. Planktonic Foraminifera are absent throughout the formation.

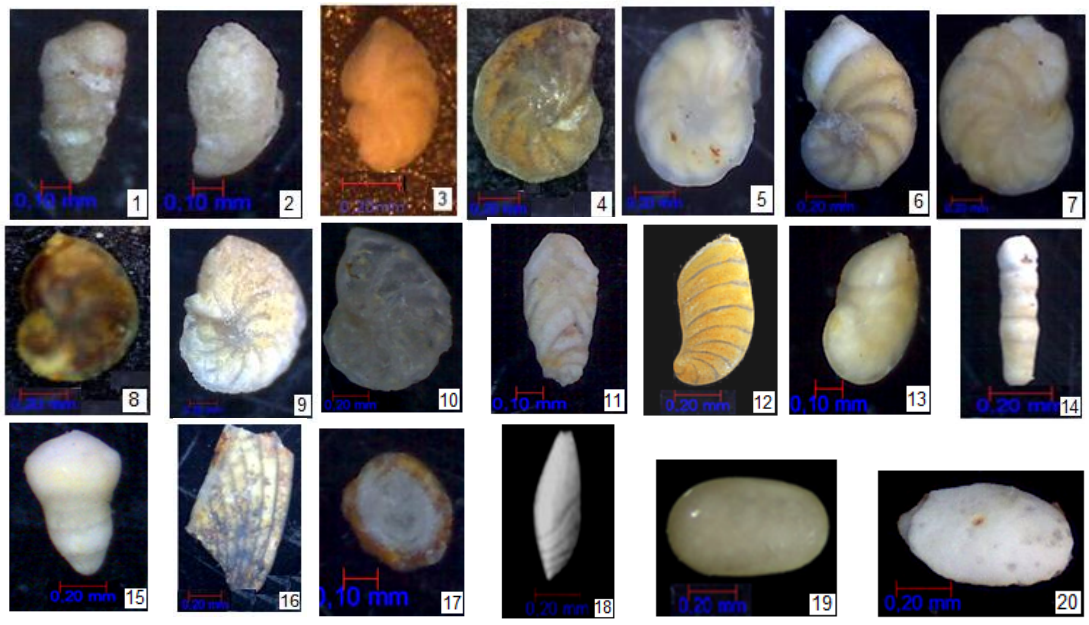


Figure 2: The microfauna found in the Antsalova site

1.*Textularia* sp. (Textulariidae), 2. *Ammobaculites* sp. (Lituolidae), 3. *Astacolus mutilatus* (Nodosariidae), 4. *Astacolus* sp. (Nodosariidae), 5. *Lenticulina* sp. (Nodosariidae), 6. *Lenticulina subtilis* (Nodosariidae), 7. *Lenticulina fracta* (Nodosariidae), 8.*Lenticulina cf. secans var angulosa* (Nodosariidae), 9. *Lenticulina tsaramandrosoensis* (Nodosariidae), 10. *Lenticulina dosineontos* (Nodosariidae), 11. *Neoflabellina lanceolata* (Nodosariidae), 12. *Planularia madagascariensis* (Nodosariidae), 13.*Saracenaria tsaramandrosoensis* (Nodosariidae), 14. *Lingulina* sp. (Nodosariidae), 15. *Rectoglandulina brandi* (Glandilunidae), 16. *Vaginulina (Citharina) sparicostata* (Glandilunidae), 17. *Spirillina tenuissima* (Spirillinidae), 18. *Globulina* sp. (Polymorphinidae), 19. *Cytherella index* (Carapace, left view) (Cytherellidae), 20. *Cytherella ex gr. Pyriformis* (Carapace, left view) (Cytherellidae).

Other fossils

Macrofossils were found in the lithology of the site namely Cephalopods (Hibolites semicanaliculatus, Actinocamax plenus, Duvalia lata, Megatheutis giganteus) and Lamellibranchs (Lamellaptychus lamellosus)

Table 1: Distribution of Benthic Foraminifera and Ostracods in the Antsalova site.

Samples / Microfauna	ATL1	ATL2	ATL3	ATL4	ATL5
Benthic foraminifera hyaline	69.00	88.00	169.00	315.00	298.00
Benthic foraminifera agglutinated	0.00	0.00	0.00	0.00	59.00
Total number of Foraminifera	69.00	88.00	169.00	315.00	357.00
Ostracods	0.00	0.00	21.00	42.00	34.00

Samples taken from the Antsalova (ATL) site offer a great wealth of microfauna (Table 1). This site is marked by a gradual increase in the number of Foraminifera (69.00 to 357.00) going from the base of the formation (ATL1) to the top (ATL5). Benthic Foraminifera are very abundant throughout the formation studied; on the other hand, planktonic forms are absent. Four species of benthic Foraminifera are left in open nomenclature: Textularia sp., Ammobaculites sp., Globulina sp., Lenticulina sp. and Ostracods are very rare or even absent in some lower levels. The subdivision of the lithological section of Antsalova is determined from the faunal composition and the facies. From bottom to top, it is made up of three levels (I, II, III). The observed numbers (ni) and theoretical numbers (ni') of microfauna species for each level are clearly very different (Table 2).

Table 2: Contingency table for the characteristic taxa of each level in the Antsalova site.

N°	LEVEL / SPECIES	I		II		III		TOTAL
		ni	ni'	ni	ni'	ni	ni'	
01	*Ammobaculites sp.*	0.00	11.00	0.00	10.00	33.00	11.00	**33.00**
02	*Textularia sp.*	0.00	9.00	0.00	8.00	26.00	9.00	**26.00**
03	*Astacolus mutilatis*	36.00	12.00	0.00	11.00	0.00	13.00	**36.00**
04	*Astacolus sp.*	0.00	13.00	0.00	12.00	39.00	13.00	**38,00**
05	*Lenticulina fracta*	0.00	18.00	52.00	16.00	0.00	18.00	**52.00**
06	*Lenticulina sp.*	91.00	64.00	96.00	57.00	0.00	65.00	**187.00**
07	*Lenticulina subtilis*	51.00	17.00	0.00	15.00	0.00	18.00	**51.00**
08	*Lenticulina dineontos*	0.00	8.00	0.00	7.00	23.00	8.00	**23.00**
09	*Lenticulina tsaramandrosoensis*	0.00	12.00	0.00	11.00	35.00	12.00	**35.00**
10	*Lenticulina secans var. angulosa*	0.00	11.00	0.00	10.00	31.00	11.00	**31.00**
11	*Planularia madagascariensis*	45.00	33.00	47.00	29.00	0.00	32.00	**92.00**
12	*Neoflabellina lanceolata*	42.00	14.00	0.00	13.00	0.00	15.00	**42.00**
13	*Globulina sp.*	61.00	44.00	41.00	40.00	27.00	45.00	**129.00**
14	*Saracenaria tsaramandrosoensis*	0.00	7.00	0.00	7.00	21.00	7.00	**21.00**
15	*Lingulina sp.*	0.00	12.00	36.00	11.00	0.00	13.00	**36.00**
16	*Vaginulina (Citharina) sparicostata*	0.00	9.00	0.00	8.00	26.00	9.00	**26.00**
17	*Rectoglandulina drandi*	0.00	7.00	0.00	6.00	19.00	7.00	**19.00**
18	*Spirillina tenuisima*	0.00	6.00	0.00	6.00	18.00	6.00	**18.00**
19	*Cytherella index*	21.00	15.00	24.00	14.00	0.00	16.00	**45.00**
20	*Cytherella ex gr. pyriformis*	0.00	25.00	18.00	23.00	55.00	25.00	**73.00**
	TOTAL	**347**		**314**		**353**		**1013**

Geochemical analysis result

Analysis of major elements in samples from the Antsalova site formation (ATL) shows that the SiO_2 contents and CaO are very high, but the other elements are generally low (TiO_2, Al_2O_3, Fe_2O3, MgO). (Table 3)

Table 3: Geochemical analysis results of samples

Samples(for each site)	Chemical elements in %							
	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Ignition loss	Humidity
ATL1	38.50	0.50	13.50	5.50	3.50	20.50	10.05	5.50
ATL2	37.05	0.30	14.50	6.50	3.05	22.30	12.50	5.05
ATL3	33.50	0.50	10.50	5.50	2.50	25.50	10.50	4.50
ATL4	35.05	0.30	3.05	5.05	2.05	30.50	9.05	0.50
ATL5	44.50	0.50	1.50	6.05	2.50	19.05	7.50	0.50

5. Discussions

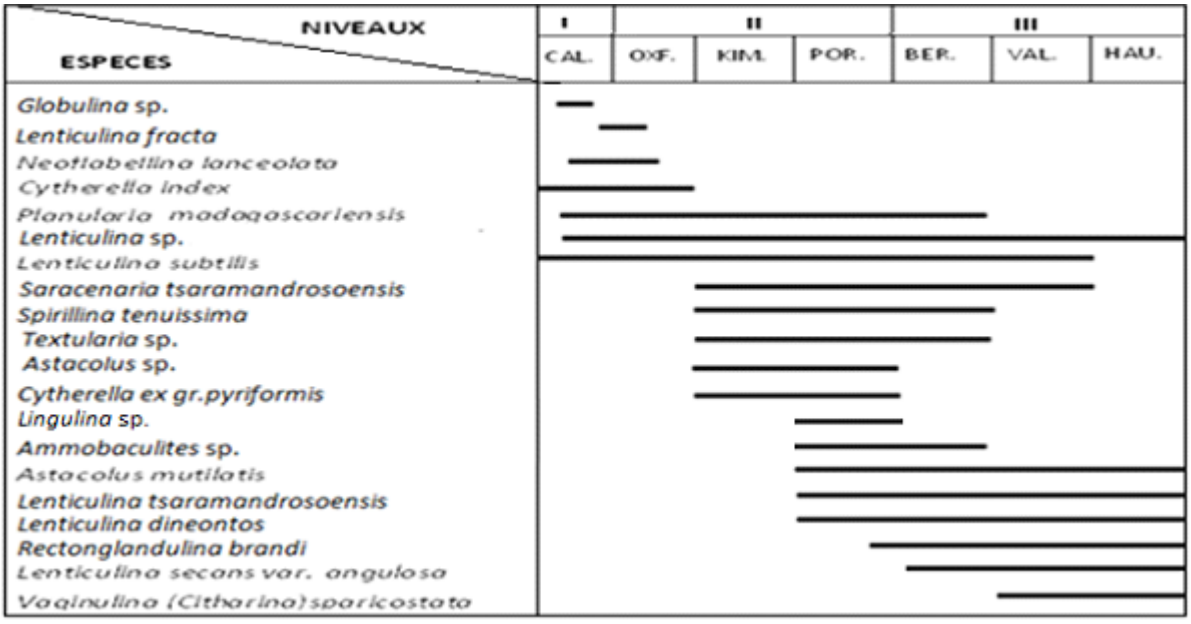
Biostratigraphy

Biozonation based on benthic Foraminifera is closely facies dependent. It takes place at the regional level and in correspondence with macrofauna which also have a good power of biochronostratigraphic resolution. The faunistic associations encountered make it possible to subdivide the formation of the Antsalova site into three levels. These three levels correspond to stratigraphic stages ranging from the Callovian to the Hauterivian:

level I: Callovian,

level II: Oxfordian - Kimmeridgian - Portlandian (Upper Jurassic),

level III: Berriasien - Valanginien – Hauterivien (Lower Cretaceous). (Figure 3)



Call. : Callovien, Oxf. : Oxfordian, Kim. : Kimmeridgien, Bér. : Berriasien, Val. : Valanginien, Hau. : Hauterivien.

Figure 4: Stratigraphic distribution of the microfauna and macrofauna encountered.

The distribution of microfauna species in the three levels (I, II, III) of the Antsalova Formation is very different. Indeed, the species encountered in each level are not the same. In order to check the difference between the diversity and the distribution of species in these three levels, it is necessary to apply the "independence test"

H_0: Species distributions and levels are independent in the Antsalova formation.

H_1: Species distributions and levels are dependent in the Antsalova formation.

$$\mathbf{X_C^2(19)= \sum_{40}^{1} \frac{(ni-ni')^2}{ni'} = 1202.04}$$

The calculated value of X_c^2 is greater than the threshold X_t^2 value read from the chi-square table for a risk of error 0.01 and degree of freedom 38, the null hypothesis is rejected. The distribution of species and the different levels in the Antsalova site are very dependent. The variation of species in the three levels confirms the stratigraphic subdivision in the Antsalova Formation from the Callovian to the Hauterivian.

The stratigraphy of the sequence studied and the stratigraphy of Hourcq V. (1950) and M. Collignon (1959- 1960) in the Antsalova region show a great similarity of sediment formation. This formation is generally made up of marls: Bélemnites marl, Duvalia marl, Ammonites marl, Bélemnites marl and Aptychus marl. The variation is manifested in the thickness of the layers, particularly for the Upper Jurassic and Lower Cretaceous (Table 4).

Table 4: Stratigraphic comparison of the present study with the stratigraphy of Hourcq V. (1950) and Collignon M. (1959-1960)

Age	**Level**	**ANTSALOVA**	
		Present site	**Hourcq V. 1950) et Collignon M. (1959- 1960)**
Lower Cretaceous	III	Greenish marl with *Duvalia lata*	Marl with *Duvalia*
Upper Jurassic	II	Greenish marl with*Bélemnites* and*Aptychus*	Marl with infillfrom limestone bank to*Hibolites* and *Aptychus*
Callovian	I	Green to grey marl	Limestone marl *Macrocephalites*

The Upper Jurassic Formation of East Africa corresponds to much more clayey and marly facies (Rajaomazava, 1992). This Formation is compatible with the deposition environments of Madagascar drift from East Africa.

Paleoecology

The paleoecological study is determined by the fossil faunal association contained in the sediments. The variation of the deposition medium is characterized from the variations of the faunas.

Certain species can then be considered as witnesses of the sedimentation environment for facies fossils.

Level I

The Nodosariidae and Polymorphinidae association prefer relatively shallow areas of continental shelves.

The fairly well-preserved forms testify to low transport and low hydrodynamics.

The CaO content is quite low, which indicates a less carbonate rich environment and the increase in the MgO percentage confirms a less hot climate at this level.

Level II

A reduction in the number of species is marked in this level. In this case, the environment is less favorable to the development of microfauna. The paleoecological interpretation of the environment is based on data provided by the nature of the sediments. The Ostracod valves are fairly well preserved, which indicates low transport and low hydrodynamics. The CaO content increases, the environment is rich in carbonate, and the decrease in the MgO proportion indicates a hot climate.

Level III

This level is marked by the predominance of Foraminifera. The genus Saracenaria is characteristic of shallow water that is 110m deep.

Ostracod valves are fairly well preserved, indicating low transport and low hydrodynamics.

The CaO content decreases, the medium is less rich in carbonate and it is confirmed by the abundance of smooth forms. The quantity in MgO is low, it results in a hot climate.

Paleobiogeography

The geographic distribution of marine microfossils (Foraminifera, Ostracods) is related to the opening of the Ocean and the subduction of the Tethys. Indeed, one can see the similarity and evolution of organisms in each part after the dislocation of the continent.

Some Genres or species of microfossils encountered in this site have been found in numerous deposits of Madagascar and also described in different countries of the world (Table 5).

Table 5: Paleobiogeographic distribution of Foraminifera and Ostracodia.

Foraminiferes and Ostracods	**Madagascar**		**Another countries**
	Espitalie and Sigal, N.Grekoff, (1963)	**Present site**	**(Espitalie et Sigal, N.Gekoff, 1963)**
Astacolus	Malakialina, Port-Berger, Tsaramandroso,	Antsalova	Amérique
Lenticulina	Antorolava, Ambanjabe, Tsaramandroso, Port- Berger	Antsalova	Allemagne
Saracenaria	Tsaramandroso	Antsalova	Allemagne, Pays-Bas
Planularia	Malakialina	Antsalova	Angleterre
Lingulina	Malakialina	Antsalova	Allemagne, Pays-Bas, Texas
Rectoglandulina	Tsararivotra, Malakialina	Antsalova	Amérique du Nord
Spirillina	Mahajanga	Antsalova	Pologne
Cytherella index	Ihopy	Antsalova	Europe Occidentale, Jura Suisse
Cytherella ex gr. pyriformis	Andranomavo, Marobaria, Mahajanga, Tsararivotra	Antsalova	Bassin de Paris

Conclusion

The biostratigraphic study of the Antsalova fossil site allows us to determine 18 species of benthic Foraminifera and 2 species of Ostracods. Based on the stratigraphic distribution of faunal associations of microfossils and macrofossils discovered, the Antsalova marl formation is subdivided into three levels:

- level I: Callovian,

- level II: Oxfordian –Portlandian (Upper Jurassic),
- level III: Berriasien – Hauterivien (Lower Cretaceous).

The site is characterized by a shallow environment of 0 to 200m, hot with normal salinity. The geographic distribution of marine microfossils (Foraminifera, Ostracods) is related to the opening of the Ocean and the subduction of the Tethys. Microfossils are very perfectionist tools for determining the age and nature of the layers traversed by drilling during prospecting or oil exploration. They are also very interesting for the realization of major works: tunnels, dams, roads, ... and this to conclude that in terms of sedimentary rocks, remember that they have container (marl or limestone) and content (microfossils and / or macrofossils), object of this study, the marl according to the results of geochemical study shows a potential of direct valorization or transformed into materials and agricultural amendments. It should be noted that marl can be used as a crop amendment product in order to make the soils less acidic, hence their necessity in agriculture and especially for development in general.

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